

HYDRATED MATERIALS ON EUROPA'S SURFACE: REVIEW OF CURRENT KNOWLEDGE AND LATEST RESULTS. T. B. McCord¹, T. M. Orlando², G. B. Hansen¹ and C. A. Hibbitts², ¹Planetary Sci. Inst., NW Div., Box 667, Winthrop WA 98862, mccordtb@aol.com, ²School of Chemistry and Biochemistry and School of Physics, Georgia Institute of Technology, Atlanta, GA 30332-0400.

Introduction: The reflectance spectra of Europa, returned by the Galileo Mission's Near Infrared Mapping Spectrometer (NIMS), very early in the investigation, showed H₂O absorptions that were interpreted by many as due to hydrated minerals. McCord et al. [1,2] showed that these absorptions were associated with material that is concentrated in the liniments and chaotic terrain, later confirmed by Fanale et al. [3], and proposed that these were due to hydrated salt minerals, mostly MgSO₄ hydrate, probably associated with the ocean below. They proceeded to demonstrate that MgSO₄ hydrate is stable over the age of the solar system on Europa's surface [4] and showed that rapidly frozen brines, as might occur when liquid is exposed on Europa or be simulated by radiation damage to crystalline material, even more closely resembled the optical properties of the Europa material [5]. MgSO₄ is thought to be a reasonable material to be found on Europa, given that it is a common product of low temperature aqueous alteration of carbonaceous chondrite material, such as occurs in the thermal evolution of bodies like the icy Galilean satellites, and is found commonly in primitive meteorites [6]. The disturbed regions on Europa seem likely places for subsurface ocean briny materials to reach the surface.

Carlson et al. [7] then suggested that a simpler explanation is that the material is sulfuric acid (H₂SO₄) created by radiolysis of sulfur with ice and they suggested a chemical cycle driven by radiation from the Jupiter magnetosphere. They presented reflectance spectra of frozen sulfuric acid hydrate that closely resembled the NIMS Europa spectrum. The source of the sulfur they suggested is probably exogenic, from sulfur ions entrained in the Jupiter magnetic field, although they allowed that sulfur in material from the ocean below might be sufficient.

Recently, Clark (Personal communication, 2003) proposed that the hydronium ion (H₃O⁺) is really what is creating the spectral signature and that this ion is present for most acids with water ice and could be due to radiation damage in water ice alone. His explanation does not require sulfates or perhaps any anionic material, but only needs water ice and radiation. He presented a spectrum of a mixture of water ice with HCL with H₂O₂ (earlier reported by Carlson et al. on Europa) and a spectrally neutral black material (carbon) that is a close match to the Europa spectrum. Our laboratory results also indicate that the cation and its solvation, not just the solvated anion, is important in affecting the spectral signatures for these materials, and that the hydronium Ion may be involved along with other effects.

It appears, from these three apparently very different explanations, that it is difficult to determine from the NIMS data available the identity of the material on Europa responsible for the NIMS spectral signature. All three types of materials seem to have reflectance spectra that closely resemble the Europa spectrum. There are small differences between the spectra presented with each of the three explanations and that for Europa, and explanations offered for these differences. A major problem is that, in spite of its major discoveries, the NIMS Europa spectra are noisy and mostly of very low spatial resolution (mostly hundreds of km per pixel, although a few postage-stamp observations of a few km per pixel were made). Further, the spectral resolution and perhaps the spectral coverage are insufficient (about 27 nm and 0.7-5 μ m) to define all the spectral features that might be helpful.

We might consider arguments other than spectral interpretations to argue plausibility. The material associated with the unusual spectral signature appears strongly concentrated in the disrupted regions on Europa—lineaments and chaotic terrain. These regions are clearly associated with processes involving the subsurface and are therefore endogenic in nature. Thus, it appears that the responsible material is from below. However, this material could be modified differently than the surrounding material by irradiation, and this modification might cause the spectral signature to change. As stated, magnesium sulfate is to be expected, even required, from thermal-chemical evolution models, along with lesser quantities of other salts, specifically Na₂SO₄. McCord et al. [4] pointed out that, while Mg (doubly bonded) is stable to radiolysis, Na (singly bonded) in sulfate is not. In fact, Na is seen coming off Europa. Abundant H⁺ may substitute for the lost Na⁺ and create H₂SO₄ (sulfuric acid). Thus, some sulfuric acid is expected if salts are present.

Both the Carlson and Clark explanations for the Europa NIMS spectral signature concern exogenically driven processes. Radiolysis of ice is expected on Europa, although clearly water ice in crystalline form persists. It is difficult to see how the spatial distribution of the spectral signature is created unless materials associated with endogenic processes are associated. Thus, all three explanations may be correct to some extent. This may be one of those "blind people feeling the elephant" situations where we don't yet have the full picture.

Clearly, we do not sufficiently understand either the suite of materials presented to the surface of Europa (from below or above) or the chemical processes that might alter them. The laboratory studies required are difficult in that the environment of Europa's surface must be simulated. Attempts are being made, however, by all three teams so far involved, and inputs from others can be expected. This question is more general than Europa and may be fundamental to the evolution and state of objects that formed with water and suffered low-temperature alteration, such as Ceres [8].

It is certainly true that better measurements of Europa are required. Fortunately, NASA recently announced a major mission back to the Icy Satellites, the Jupiter Icy Moons Orbiter (JIMO). It is likely that a more capable spectrometer and perhaps other relevant instruments will be on board and that these new data will settle the question. In the meantime, and to prepare for JIMO, studies of the chemistry of these materials are clearly required.

A review of the status of this controversy will be presented along with the latest results available at the time of the workshop. The implications for the JIMO mission science and instrument requirements will be discussed.

References:

- [1] McCord, T. B., G. B. Hansen, F. P. Fanale, R. W. Carlson, D. L. Matson, T. V. Johnson, W. D. Smythe, J. K. Crowley, P. D. Martin, A. Ocampo, C. A. Hibbitts, J. C. Granahan, and The NIMS team, (1998) Salts on Europa's surface detected by Galileo's near infrared mapping spectrometer, *Science*, 280, 1242-1245.
- [2] McCord, T. B., G. B. Hansen, D. L. Matson, T. V. Johnson, J. K. Crowley, F. P. Fanale, R. W. Carlson, W. D. Smythe, P. D. Martin, C. A. Hibbitts, J. C. Granahan, and A. Ocampo, (1999) Hydrated salt minerals on Europa's surface from the Galileo near-infrared mapping spectrometer (NIMS) investigation, *J. Geophys. Res.*, 104, 11824-11852.
- [3] Fanale, F. P., et al., (2000) Tyre and Pwyll: Galileo orbital remote sensing of mineralogy versus morphology at two selected sites on Europa, *J. Geophys. Res.*, 105, 22647-22655.
- [4] McCord, T. B., T. M. Orlando, G. Teeter, G. B. Hansen, M. T. Sieger, N. G. Petrik and L. Van Keulen, (2001) Thermal and radiation stability of the hydrated salt minerals epsomite, mirabilite and natron under Europa environmental conditions, *J. Geophys. Res.*, 106, 3311-3319.
- [5] McCord, T. B., G. Teeter, G. B. Hansen, M. T. Sieger and T. M. Orlando (2002) Brines exposed to Europa surface conditions, *J. Geophys. Res.*, 107, 10.1029/2000JE001453.
- [6] Fanale, F. P., Y. H. Li, E. Decarlo, N. Domergue-Schmidt, S. K. Sharma, K. Horton, J. C. Granahan, and the Galileo NIMS team, (1998) Laboratory simulation of the chemical evolution of Europa's aqueous phase (abstract), *Lunar Planet. Sci.*, XXIX, 1248, [CD-ROM].
- [7] Carlson, R. W., R. E. Johnson and M. S. Anderson, (1999) Sulfuric acid on Europa and the radiolytic sulfur cycle. *Science*, 286, 97-99.
- [8] McCord, T. B. and C. Sotin, (2003) Ceres: Evolution and Current state, submitted to *J. Geophys. Res.*